Influence of Culture Density on Juvenile Coho Salmon Production and Ocean Survival. Smolt Releases in 1979 and 1980 from Capilano Hatchery.

U. H. M. Fagerlund, J. R. McBride, B. S. Dosanjh,
E. T. Stone, and F. K. Sandercock

Department of Fisheries and Oceans
Fisheries Research Branch
West Vancouver Laboratory
4160 Marine Drive
West Vancouver, B. C. V7V 1N6

December 1984

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1229

Canadian Technical Report of Hydrography and Ocean Sciences

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Canadian Technical Report of

Fisheries and Aquatic Sciences No. 1229

INFLUENCE OF CULTURE DENSITY ON JUVENILE COHO SALMON PRODUCTION AND OCEAN SURVIVAL. SMOLT RELEASES IN 1979 AND 1980 FROM CAPILANO HATCHERY.

December 1983

by

U.H.M. Fagerlund[1], J.R. McBride[1], B.S. Dosanjh[1], E.T. Stone[2], and F.K. Sandercock[3]

[1] Fisheries Research Branch
Department of Fisheries and Oceans
West Vancouver Laboratory
4160 Marine Drive
West Vancouver, B.C. V7V 1N6 Canada

[2] Facility Operations
Department of Fisheries and Oceans
Capilano Salmon Hatchery
4500 Capilano Road
North Vancouver, B.C. V7R 4K2 Canada

[3] Facility Operations
Department of Fisheries and Oceans
1090 West Pender Street
Vancouver, B.C. V6E 2P1 Canada

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Cat. No. Fs 97-6/1229 ISSN 0706-6457

ABSTRACT

Fagerlund, U.H.M., J.R. McBride, B.S. Dosanjh, E.T. Stone, and F.K. Sandercock. 1983. Influence of culture density on juvenile coho salmon production and ocean survival. Smolt releases in 1979 and 1980 from Capilano hatchery. Can. Tech. Rep. Fish. Aquat. Sci. 1229: iv + 29 p.

Coho (Oncorhynchus kisutch) juveniles were reared in two consequtive studies. In the first study, fry were held at four densities for 12 months until release in early June 1979. In the second one, juveniles were raised at six densities, but only during the last five months before release in May 1980. Smolts were marked with magnetic nose tags which identified pond number and in 1980, also identified equal-numbered sub-populations of small, medium and large size fish.

Density-related effects on smolts released in 1979 have been reported earlier (Fagerlund et al. 1981). In 1980, decreased weight, length and protein content and increased condition factor and mortality were associated with high ponding density. Skewness in length distribution and correlation of condition factor with length changed from positive to negative values with increasing density. Plasma cortisol concentrations and interrenal cell nuclear diameters were not affected by changes in density. Protein and lipid content of fish generally increased and moisture and ash content decreased with increasing size of smolts.

Decreasing the ponding density markedly increased ocean survival of coho released in 1979 but only weakly affected survival of fish released in 1980. Adult females were longer and heavier than males in both years regardless of density.

Ocean survival generally increased with increasing size of smolts, but survival of sub-populations of small (mean weight 9.4-11.1 g) fish was vastly lower than that of medium (12.5-13.9 g) or large (16.2-18.0 g) size fish.

Key words: coho salmon, smolt, culture, density, survival.

RÉSUMÉ

Fagerlund, U. H. M., J. R. McBride, B. S. Dosanjh, E. T. Stone, and F. K. Sandercock. 1983. Influence of culture density on juvenile coho salmon production and ocean survival. Smolt releases in 1979 and 1980 from Capilano hatchery. Can. Tech. Rep. Fish. Aquat. Sci. 1229: iv + 29 p.

De jeunes saumons cohos (Oncorhynchus kisutch) ont été élevés aux fins de deux études consécutives. Dans la première étude, on a choisi quatre densités pour élever des alevins pendant 12 mois jusqu'à leur libération au début de juin 1979. Dans la seconde, on a choisi six densités mais seulement pendant les cinq derniers mois avant leur libération en mai 1980. On a marqué des saumoneaux au moyen d'étiquettes nasales magnétiques qui indiquaient le numéro du bassin et qui, en 1980, identifiaient également des sous-populations comptant un nombre égal de poissons de petite, de moyenne et de grande taille.

Les effets sur les saumoneaux libérés en 1979 ont été signalés plus tôt (Fagerlund et al. 1981). En 1980, une diminution du poids, de la longueur et de la teneur en protéines et une augmentation du coefficient de condition et de la mortalité ont été associés à une forte densité en bassin. Les valeurs de l'asymétrie dans la distribution des longueurs et de la corrélation du coefficient de condition avec la longueur sont passées de positives à négatives suite à une augmentation de la densité. Les concentrations d'hydrocortisone du plasma et les diamètres nucléaires des cellules interrénales n'ont pas été touchés par des changements de densité. La teneur en protéines et en lipides des poissons a généralement augmenté et la teneur en eau et en cendres a diminué à mesure que les saumoneaux grandissaient.

Une diminution de la densité en bassin a accru sensiblement la survie en mer des saumons cohos libérés en 1979, mais n'a fait varier que légèrement la survie de poissons libérés en 1980. Les femelles adultes étaient plus longues et plus lourdes que les mâles au cours des deux années quelle que soit la densité.

La survie en mer a augmenté de façon générale avec la taille des saumoneaux, mais la survie de sous-populations de petits poissons (poids moyen de 9,4 à 11,1 g) était beaucoup plus faible que celle de poissons de taille moyenne (12,5 à 13,9 g) ou de grande taille (16,2 à 18 g).

Mots-clés: saumon coho, saumoneau, culture, densité, survie.

INTRODUCTION

Since the re-introduction of salmon hatcheries in North America in the late 1950's (MacCrimmon et al. 1974) selection of culture densities has largely been based on empirical observation and economic considerations. Fish culturists attempted to achieve as high a production of apparently healthy and active smolts as physical plant and available funding would allow. The question whether culture conditions in the hatcheries were consistent with optimum adult survival was not addressed due, in part, to the absence of a technique to relate juvenile production to adult survival. The recent development of coded, magnetic nose tags makes it possible to study the effect of culture conditions on ocean survival.

It has long been recognized that crowding of fish in culture facilities affects growth, disease incidence and mortality because of decrease in available oxygen and accumulation of waste products. Only recently, however, has it been recognized that, besides this purely physical effect of crowding, a more subtle effect on the fish is caused by social interaction. The result may be chronic stress in the fish, which in turn, may affect future growth and survival. Some of this evidence has been discussed by Fagerlund et al. (1981), who reported differences in growth and other physiological parameters when coho were raised at Capilano Hatchery at four densities from the fry stage until release in 1979. Sandercock and Stone (1980, pers. comm.) demonstrated that return rates of adults originating from a 1977 release of coho smolts were inversely proportional to the pond density during culture.

In the present communication we report the final return data pertaining to jacks and adults originating from the 1979 smolt release from Capilano Hatchery. In addition, we present data for coho juveniles raised at the same hatchery and released during 1980 and the return rates of jacks and adults originating from this release.

METHODS AND MATERIALS

Smolts released in 1979 - Details regarding the rearing of coho juveniles of the 1977 brood have been provided by Fagerlund et al. (1981). These fry were loaded into four ponds in June, 1978 at densities ranging from 56,638 to 104,551 fish per pond. Mean weights of smolts released June 4, 1979 ranged from 17.7 g at the lower density to 13.8 g at the highest density. Approximately 10,000 smolts from each pond were tagged, each pond receiving a separate tag code.

Smolts released in 1980 - Coho fry, progeny of adults returned to Capilano River Hatchery in 1978, were reared until June 1979 in fiberglass troughs at a density of 35000 per m^3. In contrast to the procedure followed during the previous year final densities were not established at this time.

Instead the fry were loaded into six Burrows ponds, 24.6 m x 5.6 m x 0.9 m rectangular, circulating-water raceways (Burrows and Chenoweth 1970) at a common density, estimated to be 75,000 fish per pond. From two of these raceways 20,000 fish were transferred January 2, 1980, to two other ones, creating duplicate series of ponds with densities assumed to be 55,000, 75,000 and 95,000 fish per pond. In March 1980, 30,000 fish in each of the three ponds in one of the two series were divided into three equal sub-populations of small, medium, and large fish. Magnetic tags, coded to identify each sub-population, were injected into the noses of the fish. The size ranges for the sub-populations were based on the fork-length measurements of 200-fish random samples from each pond. The marked fish were further identified by removal of the adipose fin and then returned to their original ponds. Shortly thereafter an estimate of the number of fish in each pond was made by recording the ratio of marked to unmarked fish in a sample of 5,000 fish. At the time of ponding, it was intended to create three densities in duplicate series. However, during the stocktaking in March it was realized that densities in duplicate ponds were dissimilar, particularly at the highest density level (see Table 8). In order to facilitate the treatment of data, duplicates were nevertheless combined in some analyses. Lengths are reported as fork lengths for juveniles and adults caught in the fishery and postorbital-hypural lengths for hatchery adults.

Water flow in the raceways was estimated to be 28L/s. Fish were held under natural photoperiod and were fed Oregon moist pellets (Moore-Clarke Company, La Conner, Washington, U.S.A.), the size of which was adjusted according to the weight of the fish. Food rations during the time of the density study were calculated to be 0.4-0.6% of estimated biomass fed once per week during the winter months, January to February, when water temperature was 1-4°C. The ration increased with time to 0.7% fed 5 times a day during May (water temperature 6°C). Because of discrepancies in the original estimates of fish numbers and partly because of differences in appetite the amount of food actually fed did not entirely conform with biomass (Table 8). Total food consumption per fish was calculated from amounts fed bi-weekly divided by the corrected number of fish obtained from a mark-recapture test. To calculate food conversion efficiency the increase in average fish weight from January to June was divided by total food consumption per fish. Condition factors were calculated as weight (g)/length^3 (cm) x 100.

Adults and jacks - Data relating to escapement to the hatchery were recorded by hatchery personnel. Adults and 2-year-old fish caught in the Canadian fishery were monitored as part of the Salmonid Catch and Mark Recovery Program of the Department of Fisheries and Oceans (D. Bailey, pers. comm.). U.S. data were supplied by Washington Department of Fisheries and Alaska Department of Fish and Game, FRED Division (D. O'Conner and C. Crandle, pers. comm.). The method of calculating "estimated" returns is outlined by D. Bailey et al. (1983). Estimated total sports fishery catches were obtained by applying the awareness factor 4 to observed tag recoveries.

Analytical procedures - Histological techniques for determining interrenal nuclear diameters have been outlined by McBride and van Overbeeke (1969). Plasma cortisol concentrations were analyzed in duplicate on 10 µl aliquots of plasma using the Gamma Coat ^{125}I cortisol radioimmunoassay kit supplied by Clinical Bioassays. Proximate analysis of body composition was according to Higgs et al. (1979).

RESULTS

SMOLTS RELEASED IN 1979

Data pertaining to the growth of fish ponded in 1978 have been reported elsewhere (Fagerlund et al. 1981). A summary is provided below.

After 12 months of rearing at four loading densities ranging from 56,638 to 104,551 fish per pond, increasing density was found to be associated with significant decreases in body weight, fork length, condition factor, food conversion efficiency and fat and protein content and increases in body water content and mortality. Skewness in length distribution changed from positive to negative with increasing density. Interrenal cell nuclear diameters in small fish held at the highest density were significantly greater than in large fish at the same density or in fish of either size held at the lowest density.

SMOLTS RELEASED IN 1980

Fish ponded in 1979 were held at similar densities until January 1980, when fish were redistributed to establish differential densities. Weight and length of these fish were inversely correlated with ponding density (Table 1). This was evident in February, 56 days after ponding. Nevertheless, at the time of release differences in weight and length between ponds were still small. However, some individual differences were statistically significant. Condition factors did not show statistically significant differences until the time of release. At that time, in contrast to the trend established during earlier weighings, fish held at the lowest density grew disproportionately faster in length than in weight compared to those at the two higher densities. An estimate of weights of sub-populations of small, medium and large size fish at the time of release is shown in Table 2. Tags were not read in these samples, thus the values are not true estimates of weights of tagged fish, since all tagged fish may not have grown at proportional rates between March and June.

Analysis of correlation of condition factor on length (Table 3) showed a statistically significant shift in slope with time to negative values, indicating that with approaching smoltification the tendency to slender body shape was stronger in large fish than in small fish. A comparison between densities indicated that the tendency to negative slopes was most pronounced at medium and high densities, although differences were not statistically significant.

There was no time-dependent change in skewness in either weight or length. However, analysis of the combined data from all four sampling times showed that increasing density resulted in a statistically significant reduction in the strong positive skew of weight and a significant change from positive to negative value of the weak skew of length (Table 4). These trends

are an indication that hierarchical dominance by large individuals is reduced at high densities.

Body moisture and ash content (% of wet weight) of coho fry increased but fat content decreased from January to June (Table 5, 6 and 7). Protein content did not undergo a consistent change. Increasing density was generally associated with increasing moisture and decreasing protein, lipid and ash content. However, density-related differences in moisture and lipid content were not statistically significant at any time. Protein content, on the other hand, was significantly decreased at the highest culture density in April and at medium and high densities in June. Fish size was generally correlated directly with protein and lipid content and inversely with moisture and ash content. These differences were mostly statistically significant in January and April, but in June only lipid contents remained statistically different. Fig. 1 illustrates changes in lipid content.

Differences in food consumption (g/fish) of fish reared at various densities and released in 1980 were less than 15%. Food conversion efficiency (FCE) suggested some correlation with ponding density (Table 8) but only when each series of ponds was considered separately. Large differences between ponds were a reflection of differences in weight gain during the experimental period. The values must be regarded as inaccurate since gains in weight were small, caused by generally low water temperatures, and consequently strongly affected by inaccuracies in reported fish weights. The results contrast with those from the previous (Fagerlund et al. 1981) study when FCE was inversely correlated with ponding density.

Low density generally was associated with smaller interrenal cell nuclear diameters (Table 9). In contrast to 1979 smolts, size of fish was not directly correlated with nuclear diameter. Differences were small in 1980 and in most cases not statistically significant.

A statistical analysis of plasma cortisol concentration (Table 10) indicated that the effect of density was not significant when all six ponds were considered. However, high concentrations in fish from ponds #3 and 4 suggested that they may have been disturbed by some hatchery activity.

ADULT AND 2 YEAR-OLD FISH ORIGINATING FROM 1979 SMOLTS

The estimated number of adults per 10,000 smolts released returning to Canadian waters increased by 47.6% when culture density was reduced by 27.5% from 104,551 to 75,780 fish per pond (Table 11, Fig. 2). However, reducing the density further to 56,638 did not result in an additional increase in return rates.

Returns of adults to the U.S. fishery, in contrast to Canadian returns, were not affected by ponding density in a consistent manner.

Numbers of two year-old fish (jacks) returning to Canadian waters followed a trend similar to that of adults. The numbers returning to the hatchery as jacks ranged from 1.0 to 6.7% of total hatchery returns.

Ponding density did not affect length of adults returning to the commercial fishery (both sexes combined, Table 12). When males and females returning to the hatchery were analysed separately, length and weight of males tended to increase with increasing density, while females did not show a trend. Females were 9 to 19% longer and 42 to 90% heavier than males at all densities, but the differences were significant only at the two lowest densities.

ADULT AND TWO-YEAR-OLD FISH ORIGINATING FROM 1980 SMOLTS

In each of the two series of ponds a trend to increasing return rate with decreasing ponding density is evident, but this trend was noticably weaker than that found in returns from the 1979 smolts (Table 13, Fig. 3). Maximum increases noted were 8.4% in series 1 and 9.3% in series 2. Differences were small between numbers of adults originating from equal-numbered sub-populations of large and medium size smolts, but numbers of adults originating from small smolts were greatly reduced, regardless of ponding density.

The return rate of two-year-olds was not consistently correlated with culture density. With a few exceptions most jacks originated from "large" juveniles. In these groups, return rates of jacks ranged from 1.6 to 8.5% of total hatchery returns.

Ponding density did not influence size of returning adults of either sex (Table 14). Numbers of fish weighed or measured in the hatchery were small. Nevertheless, there was a trend to increasing length and weight of adults of either sex with increasing size of juveniles. Neither size of smolt nor culture density appeared to influence the relationship between number or size of adult males and females. Females were both longer and heavier than males, but these differences were not as large as in fish returning in 1980.

DISCUSSION

JUVENILE CHARACTERISTICS

There were obvious differences between smolts released in 1979 and 1980 in regard to their response to changes in loading density. The effect on body weight, fork-length and condition factor (Table 1) of 1980 smolts were small in comparison with those reported for the 1979 smolts (Fagerlund et al. 1981). Pronounced enlargement of interrenal cell nuclear diameters of small fish held at the maximum density found in 1979 smolts was not confirmed in 1980. Furthermore, density-related differences in body composition, particularly fat content, were larger in 1979 than in 1980 smolts. Possibly one explanation for the difference noted in the response between the two

studies can be found in the appreciably greater number of fish present in the high density group of the first study than in that of the second study (104,551 vs 91,875 or 78,379).

The suppression of positive skew of weight and the shift towards negative skew of length which occurred in both years at higher densities suggested a decrease in the relative proportion of large animals, or, alternatively, an increase in the proportion of small animals. The negative skew at high densities, however, was more pronounced in 1980 than in 1979. In both 1979 and 1980 smolt populations, negative correlation of condition factor and length at high densities indicated that at these densities a low condition factor, a characteristic of smoltification, was most prevalent in large fish. This size-dependency of smoltification was further demonstrated in a shift over the period January to June 1980 towards negative correlation coefficients. In addition, the 1980 smolts demonstrated size-related differences between sub-populations of small, medium and large size fish at each density. For instance, while lipid content in all subpopulations decreased from January to June as fish size increased (Fig. 1), at each sampling time the largest fish within a pond had the highest lipid content. At no time did small fish attain as high a lipid content as large fish.

The differences between sub-populations are consistent with the establishment of a social rank order or hierarchy. Li (1973) observed a lower fat content in sub-dominant individuals. Yamagishi (1962) and Li and Brocksen (1977) found a decreased growth rate and Ejike and Schreck (1980) observed high plasma cortisol and hepatic glycogen levels in sub-dominant rainbow trout. These findings suggest an inverse correlation between stress and dominance. The stress could lead to lower stamina, disease resistance and survival. The fact that the sub-populations are different in physiological characteristics as well as in size suggest to us that fish of different size are distinct, either through hereditary factors or factors related to dominance within the populations. Consequently these factors, primarily, and size only in a secondary sense may be the cause of the noted differences in adult survival.

EFFECT ON RETURN RATE OF ADULTS AND JACKS

In conformity with adult returns of coho raised at densities between 56,097 and 101,176 fish per pond at Capilano hatchery and released in 1977 (Sandercock and Stone, pers. comm. 1980) the rates of adult returns from the 1979 smolt release reported here were strongly influenced by ponding density. However, adult returns from the 1979 release did not increase further when the number of fish was reduced from 75,780 to 56,638, while a similar reduction in density of the 1977 smolts resulted in a 29.6% increase in adult returns. Returns of adults originating from the 1980 smolt release, in contrast to these two studies, were only weakly affected by ponding density. Although maximum ponding density was less in 1980 than in 1979 or 1977, a more notable difference between the three years was that the coho of the two earlier releases were raised at the designated densities for 12 months starting at the fry stage (June) until 12 months later while the smolts released in 1980 were retained at different densities only during their last 5 months (January to June) in fresh water. High density during the final stages of rearing in

ponds will have an effect on quality of smolts since a large biomass can (a) lead to reduced oxygen levels as well as increased accumulation of excretory products and (b) induce alterations in hierarchy resulting in social stress. Evidence for the former is commonly seen in the drop in oxygen levels that occurs when smolt-size fish in ponds are handled or otherwise disturbed. Nevertheless, even when biomass is low, such as during the early stages of rearing, territorial demands may exert pressure on the population. Knowledge regarding the social interaction of salmonids in culture facilities is still scant. However, recent reports have demonstrated the importance of culture density during early life stages of coho salmon (Birks et al. 1981) and steelhead trout (Loftus 1982). These studies, carried out under laboratory conditions, indicated that very young salmon quickly responded to increases in number of fish per volume by decreasing their growth rates, presumably influenced by the stress of social interaction, while later on growth rates converged to a common level presumably governed more by genetic and nutritional factors.

The results presented here, in support of the cited evidence, suggest that ponding density during the early fry stage has a significant influence on smolt quality and ocean survival. It would be of interest to test whether restricting the period of testing to the early life stage would result in differences in ocean survival.

Recently, Bilton et al. (1981) have shown that the size of smolts and time of release of coho influences the return rate of adults. These studies have been extended to include coho reared at Capilano Hatchery (Bilton et al. 1982), but adult return data are not available at this time. It should be noted, that in all three density studies at Capilano the release time of the smolts coincided with that of the main smolt production at Capilano hatchery. While there was a considerable density-dependent difference in smolt size of the groups in our first study, little variation was evident in the second. Differences in size in the first study may have influenced adult return rates. However, in an earlier coho release from Capilano (Sandercock and Stone, pers. comm. 1980) a decrease in loading density from 101,176 to 56,097 resulted in an 84% increase in ocean survival, while, according to hatchery records, the difference in average smolt weight (14.4 and 15.6 g, respectively) was small. Consequently, a strong influence of density on ocean survival was indicated. This viewpoint is supported by the evidence presented here and by Fagerlund et al. (1981) which shows that high pond density causes significant stress-related physiological changes in the juveniles, which may affect survival during the adult stage.

ACKNOWLEDGMENTS

We appreciate the assistance provided by Capilano Hatchery personnel. Helen Dye performed the cortisol analyses and Mrs. Herminia Sy histological preparations and Morva Young efficiently typed the manuscript.

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TABLE 1. Weight, length and condition factor of coho released from Capilano Hatchery in 1980. Values are means and standard errors of the mean(SEM) of 400 fish, 200 from each of 2 replicate groups. For loading density of replicates please refer to Table 10.

Time of sampling	Loading density Low	Medium	High
Weight (g)			
January 17	11.0[b,c]*	10.6[a,b]	11.3[c,d]
February 27	11.4[c,d]	10.2[a]	10.5[a,b]
April 11	11.7[d]	10.8[b]	10.8[b]
June 4	13.6[f]	13.1[f]	12.7[e]
	(14.1, 13.2)**	(14.1, 12.3)	(13.0, 12.5)
SEM		0.2	
Length (cm)			
January	9.8[a,b]	9.7[a]	9.9[b,c,d]
February	10.2[f,g]	9.9[b,c]	10.0[c,d,e]
April	10.3[g]	10.1[e,f]	10.0[d,e]
June	11.2[j]	11.1[i]	10.9[h]
SEM		0.05	
Condition factor			
January	1.13[e]	1.12[e]	1.12[e]
February	1.04[d]	1.02[c]	1.03[c,d]
April	1.04[d]	1.03[c,d]	1.03[c,d]
June	0.94[a]	0.96[b]	0.96[b]
SEM		0.004	

* Values carrying a common letter are not significantly different (Duncan's multiple range test, $\alpha = 0.05$). Analysis of variance indicated significant effects on weight, length and condition factor of the following variables: replicate, replicate x density, time and density x time. Condition factor was also affected by length of fish and time x length.

** Replicates 1 and 2, respectively.

TABLE 2. Weight distribution (g, mean ± SD) in equal-numbered sub-populations of small, medium and large size coho in samples of 200 fish taken at the time of release in June 1980.

Size group	No. of smolts released 49,479	70,377	78,379
Small	10.5 ± 1.8	11.1 ± 1.7	9.4 ± 1.7
Medium	13.9 ± 2.4	13.9 ± 1.4	12.5 ± 1.2
Large	18.0 ± 2.6	17.2 ± 2.8	16.2 ± 2.1

TABLE 3. Linear correlation of condition factor and length of juvenile coho salmon released in 1980. Values are covariate slopes and standard errors of combined samples of 200 fish from each of six ponds. Number of data points are shown in brackets.

	All densities	
January 17	$0.0045^{b,c}$*	± 0.0020 (1200)
February 27	0.0117^{c}	± 0.0022 (1200)
April 11	0.0031^{b}	± 0.0021 (1200)
June 2	-0.0067^{a}	± 0.0025 (1200)

	Density** Low	Medium	High
June 2	0.0002α ± 0.0041	-0.0084α ± 0.0045	-0.0089α ± 0.0042

* Values carrying a common letter are not significantly different (Duncan's multiple range test, α = 0.05). Arabic and Greek superscripts refer to separate block analyses. For results of analysis of variance please refer to Table 1.

** Replicate ponds were pooled. N = 400.

TABLE 4. Skewness (mean ± SD) in the frequency distribution of weight and length in samples of 200 fish taken from duplicate ponds in January, February, April and June, 1980. N = 800.

	Density		
	Low	Medium	High
Weight	1.03β* ± 0.31	0.58α ± 0.30	0.53α ± 0.28
Length	0.17β ± 0.23	-0.19α ± 0.26	-0.13α ± 0.21

* Values carrying a common letter are not significantly different (Duncan's multiple range test, α = 0.05). Analysis of variance indicated a significant effect of density.

TABLE 5. Body composition of juveniles taken January 22, 1980 from the Capilano Hatchery. Values are means and standard errors of the mean (in brackets) of three samples from each of two replicate ponds. Each sample consisted of five fish. For definition of sub-populations please refer to text.

Size of fish	Loading density Low	Medium	High	Row means
Moisture (%)				
Small	74.9^{c,*}	75.2^{c}	75.4^{c}	75.2γ
Medium	73.0^{a,b}	73.8^{b}	73.4^{b}	73.4β
Large	72.5^{a}	72.4^{a}	73.3^{a,b}	72.7α
SEM		0.3		0.2
Column means	73.5α	73.8α	74.1α	
SEM	0.2			
Protein (%)				
Small	16.3^{b,c}	16.3^{b,c}	16.0^{a,b,c}	16.2α
Medium	16.4^{c}	16.2^{b,c}	16.3^{c}	16.3α
Large	16.4^{c}	16.4^{c}	16.2^{b,c}	16.3α
SEM		0.2		0.1
Column means	16.3β	16.3β	16.2αβ	
SEM		0.1		
Lipid (%)				
Small	6.74^{b}	6.43^{a,b}	6.38^{a,b}	6.51α
Medium	8.55^{d,e}	7.74^{c}	7.90^{c,d}	8.06β
Large	8.98^{e}	8.84^{e}	7.98^{c,d}	8.60γ
SEM		0.26		0.15
Column means	8.09α	7.67α	7.42α	
SEM		0.15		
Ash (%)				
Small	2.45^{a,b,c,d}	2.58^{c,d}	2.35^{a,b,c,d}	2.46β
Medium	2.27^{a,b,c}	2.32^{a,b,c}	2.34^{a,b,c}	2.31αβ
Large	2.27^{a,b,c}	2.25^{a,b,c}	2.14^{a}	2.22α
SEM		0.11		0.06
Column means	2.33α	2.39α	2.28α	
SEM		0.06		

* Duncan's multiple range test. Values carrying a common letter are not significantly different ($\alpha = 0.05$). The effect of density and size alone were determined in separate tests. For results of analysis of variance please refer to Table 6.

TABLE 6 - Body composition of juveniles taken April 18, 1980. Values are means and standard errors of the mean (in brackets) of five samples from each of two replicate ponds. Each sample consisted of five fish.

Size of fish	Loading density Low	Medium	High	Row means
Moisture (%)				
Small	$77.1^{b,*}$	78.1^{c}	78.6^{c}	77.9γ
Medium	75.6^{a}	77.2^{b}	76.8^{b}	76.6β
Large	75.4^{a}	75.2^{a}	75.5^{a}	75.3α
SEM		0.2		0.1
Column means	76.0α	76.8α	77.0α	
SEM		0.1		
Protein (%)				
Small	$15.3^{b,c}$	$15.5^{c,d}$	14.6^{a}	15.1α
Medium	$15.8^{c,d,e,f}$	$15.6^{c,d,e}$	$14.8^{a,b}$	15.4β
Large	$15.9^{d,e,f}$	$15.9^{d,e,f}$	$15.7^{c,d,e,f}$	15.9γ
SEM		0.2		0.1
Column means	15.7β	15.7β	15.1α	
SEM		0.1		
Lipid (%)				
Small	4.16^{b}	3.35^{a}	3.45^{a}	3.65α
Medium	$5.13^{c,d}$	4.74^{c}	$5.10^{c,d}$	4.99β
Large	$5.98^{e,f}$	$6.47^{f,g}$	$5.67^{d,e}$	6.04γ
SEM		0.20		0.11
Column means	5.09α	4.85α	4.74α	
SEM		0.11		
Ash (%)				
Small	$2.52^{c,d}$	2.67^{d}	$2.47^{b,c,d}$	2.55γ
Medium	$2.42^{a,b,c,d}$	2.66^{d}	$2.32^{a,b,c}$	2.47β
Large	$2.42^{a,b,c,d}$	$2.21^{a,b}$	$2.35^{a,b,c}$	2.33αβ
SEM		0.08		0.05
Column means	2.46α	2.52α	2.38α	
SEM		0.05		

* Duncan's multiple range test. Values carrying a common letter are not significantly different ($\alpha = 0.05$). The effect of density and size alone were determined in separate tests.

Analysis of variance was carried out on pooled data from January and April. Significant effects of the following variables were noted.

Body constituent	Variable
Moisture	time, fish size, replicate, time x replicate
Protein	time, fish size, time x fish size, replicate
Lipid	time, fish size, replicate, time x replicate
Ash	fish size, replicate, time x replicate

TABLE 7 - Body composition of coho smolts taken June 4, 1980 before release from the hatchery. Values are means and standard errors of the mean (in brackets) of eight samples (small and large fish) or four samples (medium fish) from each of two replicate ponds. Each sample was made up of two fish. Fork length of sampled fish are shown (means ± SD).

Size of fish	Loading density Low	Medium	High	Row means
Moisture (%)				
Small	77.2[a]*	76.9[a]	78.5[b]	77.6α
Medium	76.7[a]	76.6[a]	76.6[a]	76.6α
Large	75.9[a]	76.3[a]	76.6[a]	76.2α
SEM		0.4		0.3
Column means	76.6α	76.6α	77.4α	
SEM		0.3		
Protein (%)				
Small	16.2[a,b]	16.2[a,b]	15.8[a]	16.1α
Medium	16.9[b]	16.7[a,b]	16.5[a,b]	16.7α
Large	16.8[a,b]	16.7[a,b]	16.1[a,b]	16.5α
SEM		0.3		0.2
Column means	16.6β	16.5β	16.1α	
SEM		0.1		
Lipid (%)				
Small	2.91[a,b]	3.06[a,b,c]	2.57[a]	2.85α
Medium	3.46[c,d]	3.03[a,b,c]	3.35[b,c,d]	3.28β
Large	3.88[d]	3.64[d]	3.68[d]	3.73α
SEM		0.20		0.13
Column means	3.41α	3.28α	3.17α	
SEM		0.10		
Ash (%)				
Small	2.64[a,b,c]	2.96[c]	2.55[a,b]	2.72α
Medium	2.59[a,b,c]	2.78[b,c]	2.26[a]	2.54α
Large	2.67[b,c]	2.54[a,b,c]	2.47[a,b,c]	2.56α
SEM		0.12		0.09
Column means	2.64β	2.76β	2.46α	
SEM		0.06		
Length (mm) of fish in samples				
Small	10.0 ± 0.7	10.0 ± 0.7	9.8 ± 0.5	
Medium	11.1 ± 0.3	11.0 ± 0.4	10.9 ± 0.2	
Large	12.2 ± 0.6	12.1 ± 0.7	11.9 ± 0.5	

TABLE 7. cont.

* Duncan's multiple range test. Values carrying a common letter are not significantly different ($\alpha = 0.05$).
Analysis of variance indicated significant effects of the following variables:

Body constituent	Variable
Moisture	density
Protein	density, density x replicate, replicate x size
Fat	size, replicate
Ash	density

TABLE 8 - Food consumption, food conversion efficiency and mortality of juvenile coho between January 2 and June 6, 1980.

	Series 1*			Series 2		
	No. of fish at time of release					
	49,410	70,313	78,195	51,329	63,105	91,811
Food consumption (g/fish)	6.2	5.6	5.7	5.9	6.0	5.4
Weight gain (g)	1.6	2.2	0.4	3.8	3.2	2.3
Food conversion efficiency (g gain/g food)	0.26	0.39	0.07	0.67	0.54	0.43
Mortality (%)	1.2	1.2	1.9	0.6	0.5	0.7

* Spatially ponds were arranged in the order appearing in the Table. Differential densities were created January 2, 1980 by transferring 20,000 fish from the first pond in each series to the third pond (see p. 2).

TABLE 9 - Interrenal cell nuclear diameters of (μm) coho smolts sampled June 4, 1980. Values are means of 25 measurements from each of 8 fish. Standard error of all means was 0.03.

Series 1	No. of fish released 49,410	70,313	78,195	Row means
Size of fish				
Small	$6.21^{a,b,c,d,*}$	$6.36^{c,d}$	$6.28^{b,c,d}$	$6.28^{a,b}$
Medium	$6.18^{a,b,c}$	$6.32^{b,c,d}$	$6.25^{a,b,c,d}$	6.25^{a}
Large	$6.27^{b,c,d}$	6.39^{d}	6.43^{d}	6.36^{b}
Column means	$6.22^{a,b}$	6.36^{c}	$6.30^{b,c}$	
Series 2	**No. of fish released 51,329**	**63,105**	**91,811**	**Row means**
Size of fish				
Small	$6.16^{a,b}$	$6.27^{b,c,d}$	$6.17^{a,b,c}$	6.20^{a}
Medium	6.07^{a}	$6.29^{b,c,d}$	6.39^{d}	6.25^{a}
Large	$6.21^{a,b,c,d}$	$6.26^{a,b,c,d}$	$6.23^{a,b,c,d}$	6.23^{a}
Column means	6.14^{a}	$6.27^{b,c}$	$6.26^{b,c}$	

* Duncan's multiple range test. Values carrying a common letter are not significantly different ($\alpha = 0.05$). Analysis of variance indicated significant effects of density ($P = 0.00036$), replicate ($P = 0.011$) and fish ($P = 0$).

TABLE 10 - Cortisol concentrations (ng/ml) in plasma of coho smolts at time of release in June, 1980. Batches of 8-10 fish were removed by dip net and anaesthetized. Blood samples were obtained within 7 min from capture.

	Series 1			Series 2		
	No. of fish at time of release					
	49,410	70,313	78,195	51,329	63,105	91,811
Mean	78.1	34.5	26.2	17.4	14.4	15.7
SD	34.2	13.7	14.5	2.6	2.2	4.2
Number of fish	40	40	40	10	10	10
Pond number*	3	4	6	7	9	10

* Pond number corresponded to the order of proximity to the area of general hatchery activity.
Analysis of variance ($P = 0.05$) indicated that density, relative size of fish and length of time spent in obtaining blood did not significantly affect cortisol concentrations.

TABLE 11 - Number of adults (1980 and 1981 returns) and jacks (1979 returns) originating from smolts released in 1979. Values represent returns per 10,000 tags released.

No. of smolts per pond	Smolt size (g)	Commercial fishery Troll Adults	Troll Jacks	Net Adults	Net Jacks	Sports fishery Adults	Sports fishery Jacks	Fishery total Adults	Fishery total Jacks	Hatchery Adults	Hatchery Jacks	Canadian total Adults	Canadian total Jacks	U.S. fishery Adults	Grand total Adults
56,638	17.7	34*	-	26	-	148	2	208	2	492	33	700	35	33	733
		129**	-	48	-	592	8	769	8	492	33	1261	41	94	1355
75,780	16.6	33*	-	25	-	164	1	223	1	485	35	708	36	40	748
		129**	-	44	-	657	4	829	4	485	35	1314	39	92	1406
84,387	15.4	29*	-	23	-	104	-	156	-	370	13	526	13	46	572
		90**	-	44	-	416	-	549	-	370	13	919	13	114	1033
104,551	13.8	24*	-	18	-	102	-	143	-	348	7	491	7	42	533
		97**	-	38	-	408	-	542	-	348	7	890	7	99	989

* Observed tags.
** Estimated returns (see text).

TABLE 12. Length and weight of adults (1980 returns) originating from smolts released in 1979. Length data were recorded for the majority of tagged fish recovered in the fishery, but only a fraction of those returned to the hatchery were measured or weighed. Number of fish in brackets. Differences in length or weight between density groups were not statistically significant in pair-wise t-tests. (M - males; F - females)

No. of smolts released	Smolt size (g)	Commercial fishery Length (mm) M + F	Hatchery returns					
			Length (mm)			Weight (kg)		
			M	F	F/M	M	F	F/M
56638	17.7	543 ± 51 (124)	399 ± 77 (12)	473 ± 37* (23)	1.19	1.11 ± 0.66 (8)	2.11 ± 0.50* (15)	1.90
75780	16.6	548 ± 54 (138)	394 ± 44 (9)	474 ± 40* (44)	1.20	1.18 ± 0.42 (7)	2.27 ± 0.78* (22)	1.92
84387	15.4	550 ± 46 (132)	414 ± 64 (6)	465 ± 44 (30)	1.12	1.19 ± 0.29 (3)	1.66 ± 0.32 (4)	1.39
104551	13.8	546 ± 50 (109)	427 ± 66 (6)	467 ± 42 (35)	1.09	1.40 ± 0.42 (4)	1.99 ± 0.78 (10)	1.42

* Significantly different from males (t - test, $P < 0.05$).

TABLE 13 - Number of adults (1981 and 1982 returns) and jacks (1980 returns) originating from smolts released in 1980. Values represent return per 10,000 tags released.

No. of smolts per pond	Sub-population	Commercial fishery: Troll Adults	Troll Jacks	Net Adults	Net Jacks	Sports fishery Adults	Sports fishery Jacks	Fishery total Adults	Fishery total Jacks	Hatchery Adults	Hatchery Jacks	Canadian total Adults	Canadian total Jacks	U.S. fishery Adults	Grand total Adults
49,410	Small	26*	-	20	-	117	-	163	-	278	1	441	1	94	535
		148**	-	141	-	468	-	757	-	278	1	1035	1	306	1341
	Medium	39*	-	50	1	223	-	312	1	357	-	669	1	121	790
		249**	-	223	3	892	-	1364	3	357	-	1721	3	386	2107
	Large	41*	-	55	-	251	1	347	1	368	34	715	35	137	852
		207**	-	303	-	1004	4	1514	4	368	34	1882	38	457	2339
	Total	35*	-	42	-	197	-	274	-	334	12	608	12	117	726
		201**	-	222	1	788	1	1212	1	334	12	1546	14	383	1929
70,313	Small	20*	-	26	-	143	-	189	-	222	-	411	-	79	490
		103**	-	106	-	572	-	781	-	222	-	1003	-	198	1201
	Medium	38*	-	38	-	218	1	294	1	382	-	676	1	117	793
		148**	-	192	-	872	4	1212	4	382	-	1594	4	357	1951
	Large	34*	-	58	-	267	-	359	-	422	25	781	25	131	912
		148**	-	288	-	1068	-	1504	-	422	-	1926	25	397	2323
	Total	31*	-	41	-	209	-	281	-	342	8	623	9	109	723
		133**	-	195	-	836	1	1164	1	342	-	1506	10	317	1825
78,195	Small	24*	-	24	-	129	-	177	-	339	-	516	-	77	593
		128**	-	110	-	516	-	754	-	339	-	1093	-	221	1314
	Medium	33*	-	47	-	219	-	299	-	431	-	730	-	126	856
		203**	-	243	-	876	-	1322	-	431	-	1753	-	415	2168
	Large	28*	-	44	2	187	1	259	3	381	6	640	9	109	749
		186**	-	228	4	748	4	1162	8	381	6	1543	14	311	1854
	Total	28*	-	38	1	178	-	245	1	384	2	629	3	104	733
		172**	-	194	1	712	1	1078	3	384	2	1462	5	316	1779

Table 13. cont.

51,329	38*	-	49	-	176	2	263	2	419	22	682	24	122	804
	203**	-	230	-	704	8	1137	8	-	-	1556	30	395	1951
63,105	39*	-	46	-	182	1	267	1	380	14	647	15	131	778
	249**	-	212	1	728	4	1189	5	-	-	1569	19	447	2016
91,811	49*	-	38	-	157	1	244	1	357	24	601	25	107	708
	324**	-	173	-	628	4	1125	4	-	-	1482	28	362	1844

* Observed tags
** Estimated returns (see text).

TABLE 14 - Length and weight of adults originating from smolts released in 1980 (1981 returns). Means are weighted. Numbers of fish in brackets. (M - males; F - females)

No. of smolts per pond	Sub-population	Commercial fishery Length (mm) M + F	Hatchery returns Length (mm) M	Length (mm) F	Length (mm) F/M	Weight (kg) M	Weight (kg) F	Weight (kg) F/M
49,410	Small	502 ± 48 (47)	396 ± 53 (8)	428 ± 47 (14)	1.08	1.25 ± 0.48 (5)	1.86 ± 0.45 (6)	1.49
	Medium	525 ± 51 (94)	394 ± 52 (13)	444 ± 60* (22)	1.13	1.55 ± 0.66 (5)	1.74 ± 0.56 (8)	1.12
	Large	535 ± 55 (104)	417 ± 37 (12)	463 ± 42* (20)	1.11	1.66 ± 0.46 (5)	2.61 ± 0.94 (6)	1.57
	Mean	525 ± 53 (245)	403 ± 47 (33)	447 ± 52* (56)	1.10	1.49 ± 0.53 (15)	2.04 ± 0.74* (20)	1.37
70,313	Small	498 ± 45 (51)	396 ± 36 (5)	422 ± 53 (13)	1.06	1.03 ± 0.13 (3)	1.25 ± 0.40 (6)	1.21
	Medium	523 ± 58 (81)	392 ± 44 (18)	428 ± 41* (26)	1.09	1.34 ± 0.42 (9)	1.66 ± 0.35 (9)	1.24
	Large	533 ± 71 (102)	408 ± 58 (21)	430 ± 57 (18)	1.05	1.32 ± 0.51 (8)	1.84 ± 0.63 (9)	1.39
	Mean	522 ± 49 (234)	400 ± 50 (44)	427 ± 49* (57)	1.07	1.23 ± 0.43 (20)	1.63 ± 0.52* (24)	1.26
78,195	Small	502 ± 49 (48)	401 ± 37 (14)	424 ± 51 (16)	1.06	1.44 ± 0.40 (9)	1.40 ± 0.46 (11)	0.97
	Medium	519 ± 46 (84)	402 ± 42 (8)	438 ± 39 (28)	1.09	1.47 ± 0.49 (6)	1.67 ± 0.41 (14)	1.14
	Large	532 ± 45 (77)	431 ± 45 (22)	446 ± 51 (22)	1.03	1.76 ± 0.56 (10)	2.21 ± 0.66 (10)	1.26
	Mean	520 ± 48 (209)	416 ± 44 (44)	437 ± 47* (66)	1.05	1.57 ± 0.50 (25)	1.74 ± 0.59 (35)	1.11
51,329		520 ± 56 (92)	389 ± 34 (27)	434 ± 41* (43)	1.12	1.39 ± 0.35 (19)	1.75 ± 0.59* (19)	1.26
63,105		528 ± 61 (92)	394 ± 54 (22)	437 ± 49* (32)	1.11	1.46 ± 0.73 (17)	1.86 ± 0.29 (9)	1.27
91,811		524 ± 53 (91)	409 ± 36 (30)	441 ± 39* (51)	1.08	1.53 ± 0.57 (21)	1.92 ± 0.51 (24)	1.25

* Significantly different from males (t-test, $P < 0.05$).

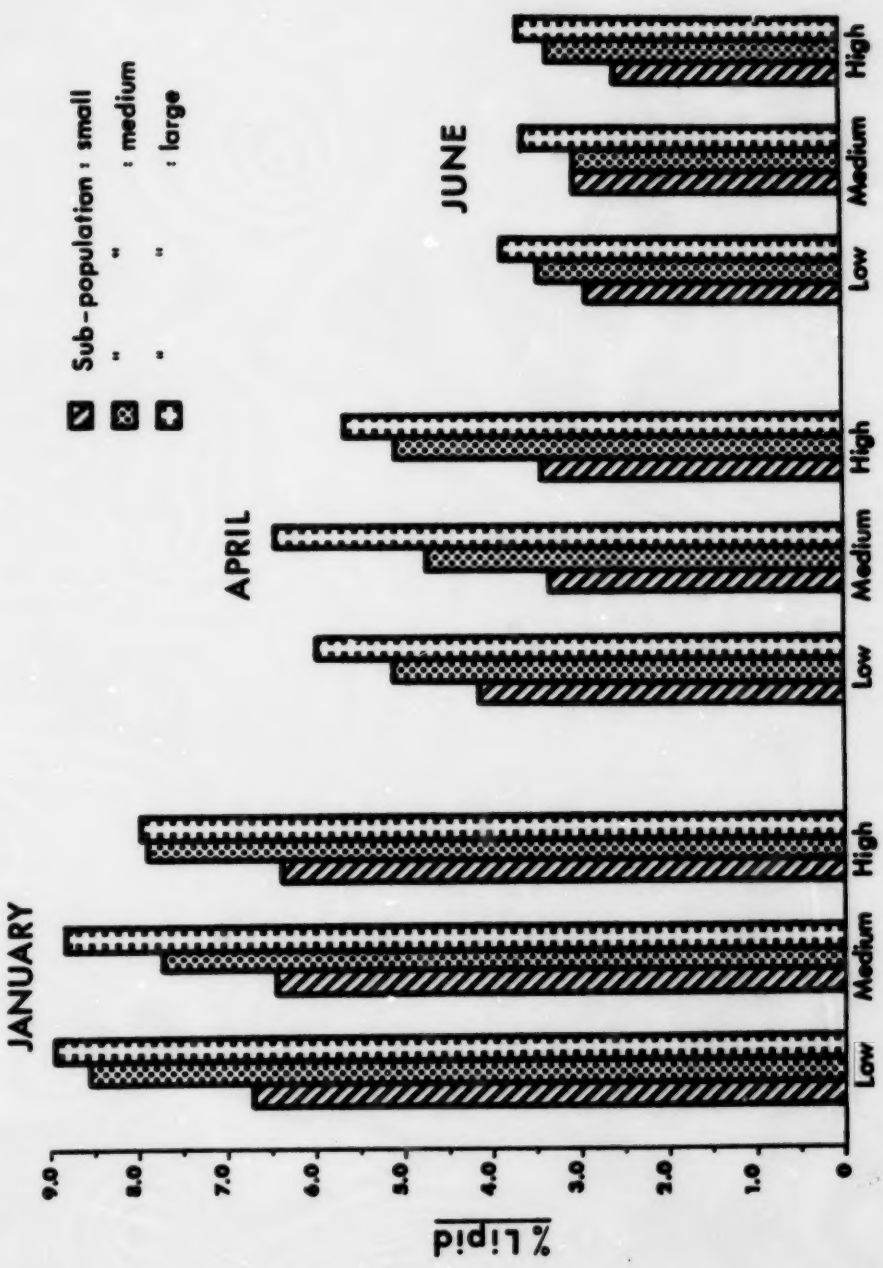

Figure 1. Effect of rearing density on lipid content of juvenile coho salmon in January, April and June, 1980. For further details please refer to Table 5, 6 and 7.

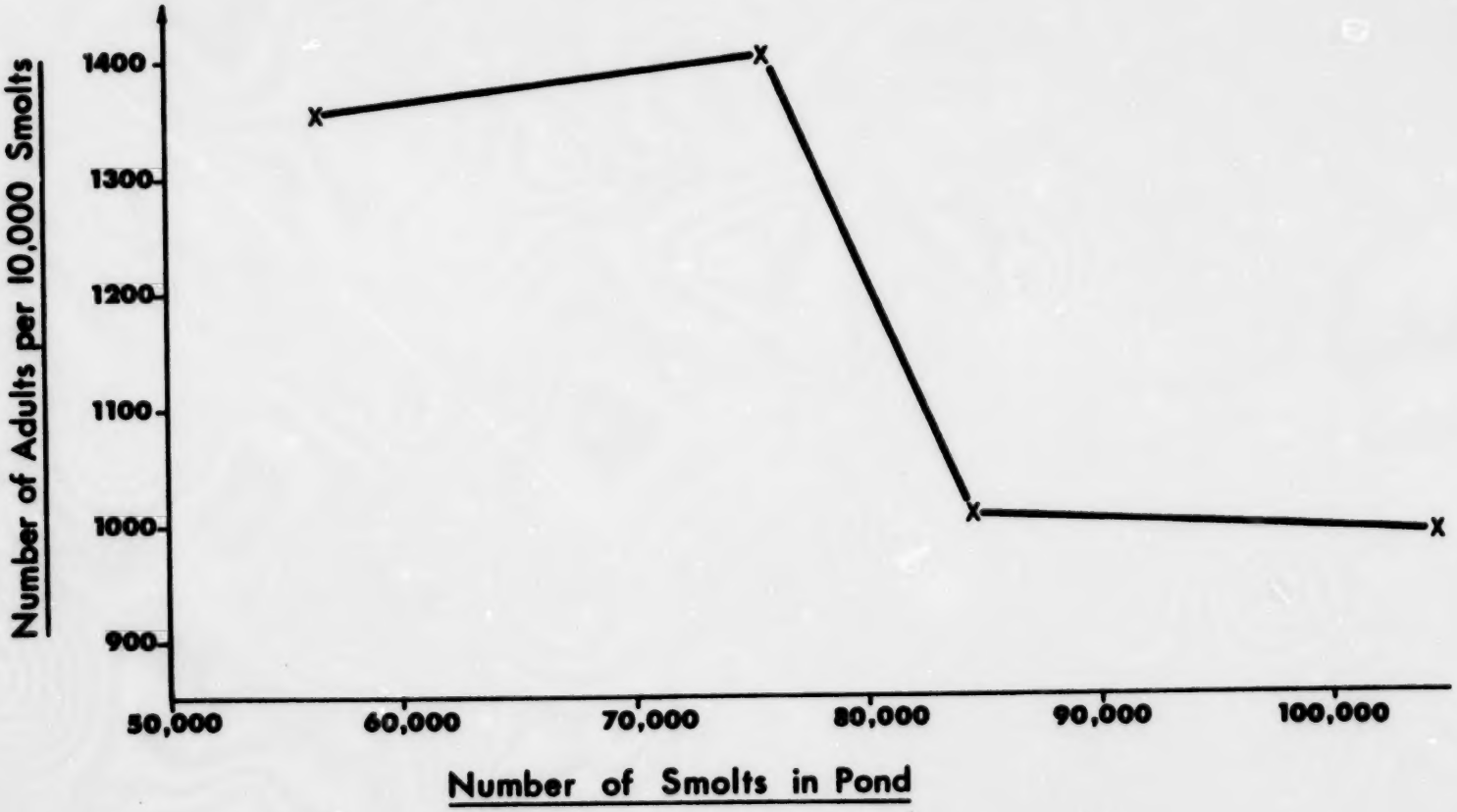

Figure 2. Estimated total number of adult coho returned to the Canadian and U.S. fisheries and to the Capilano Hatchery calculated per 10,000 coho smolts released in 1979.

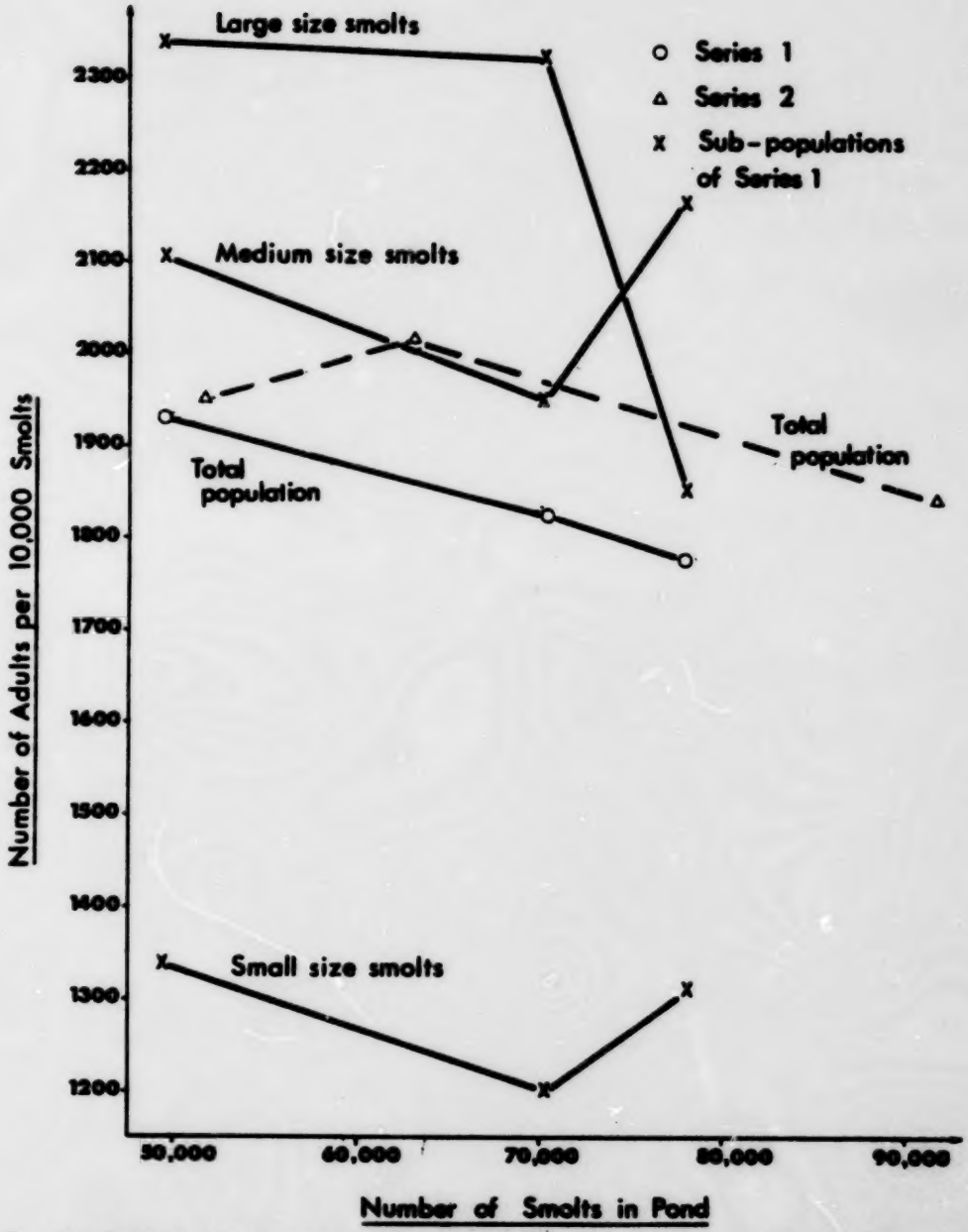

Figure 3. Estimated total number of adult coho returned to the Canadian and U.S. fisheries and to the Capilano Hatchery calculated per 10,000 smolts released in 1980. For weights of small, medium and large size smolts please refer to Table 1.